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AN ANALYSIS INTO THE PRIORITIZATION OF MAINTENANCE ACTIONS IN THE AIR FORCE CIVIL ENGINEERING RECURRING MAINTENANCE PROGRAM

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This thesis analyzed the Air Force Civil Engineering Recurring Maintenance Program. The analysis focused on the collection of decision factors important in the prioritization of maintenance items and the development of a systematic procedure for prioritization. Decision factors were collected through personal interviews with maintenance personnel at Wright-Patterson AFB and private organizations located in the Dayton, Ohio, area. These decision factors represent the thought process used in prioritization of maintenance items. The systematic procedure was developed using these decision factors. This systematic procedure was developed as a two part procedure. Part one uses a pairwise comparison technique to rank order the decision factors. The pairwise comparison establishes the flexibility necessary for incorporation into any preventative maintenance program. Part two then completes the procedure by calculating the maintenance priority number. The maintenance priority number indicates the relative importance of the maintenance item in relation to other items in the inventory.

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# AN ANALYSIS INTO THE PRIORITIZATION OF MAINTENANCE ACTIONS IN THE AIR FORCE CIVIL ENGINEERING RECURRING MAINTENANCE PROGRAM

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

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# Chapter 1

## BACKGROUND

The goal of Base Civil Engineering (BCE) maintenance management is to "provide an operational installation capable of supporting the mission, including the development and implementation of programs designed to enhance the livability of the base community [17:1-1]." To accomplish this goal the BCE organization must use all available resources efficiently and effectively in meeting work requirements. One such program designed to support this goal is the Air Force Civil Engineering Recurring Maintenance Program. (Hereafter this program will be addressed simply as RMP.)

The RMP is a preventative maintenance program with the objective to maximize equipment life expectancy at a minimum cost. Although programs such as the RMP lack the visibility and luster of new construction projects, or sophisticated weapon systems; when properly operated, a preventative maintenance program can significantly aid in reducing maintenance costs (1:620).

Unfortunately, shrinking budgets and increasing costs do not allow for the improvements and additions organizations would many times like to make. This fact makes preventative maintenance essential. Backed by the same reasoning, organizational workloads require that high priority work be accomplished, often this is at the expense of a program such as the RMP. A maintenance program that operates efficiently and effectively is the exception rather than the rule (1:619).

## LITERATURE REVIEW

The purpose of the maintenance function in an organization is to maintain the reliability of an operating system at a specified level, and to minimize costs (1:597). This objective can be met in two ways: (1) by reducing the frequency of failure, and (2) by reducing the severity of failure. Programs and policies that tend to reduce the frequency of failure are: preventative maintenance, education of personnel, simplification of operation, and early replacement (1:597). Programs and policies that tend to reduce the severity of failure are: simplifying the task of repair, and increase of repair service (1:597). This research will address programs and policies that tend to reduce the frequency of failure. Specifically, the programs and policies of preventative maintenance.

Preventative maintenance can be defined as "maintenance performed prior to breakdown and may be either minor in nature, such as a simple repair, or major, such as a complete overhaul or replacement [1:592]." Generally, the maintenance actions to be performed, such as remedial repair, or major overhaul, are scheduled for accomplishment at predetermined time periods; usually after n hours of operation or at set periods throughout the calendar year (e.g., weekly or monthly).

Preventative maintenance can be justified according to the following points: (1) it is more economical to maintain a piece of equipment while it is operational than to operate the equipment to the point of failure, and (2) the probability of equipment breakdown can accurately be predicted (1:620). (An assumption of this research will be that the two points cited above are accurate reflections of equipment contained in the Air Force Civil Engineering RMP inventory.)

Within the Air Force, the program designed to accomplish this function is the Air Force Civil Engineering Recurring Maintenance Program (RMP). The purpose of the RMP is threefold:

> . . . to prolong the life expectancy of facilities and equipment, to minimize equipment breakdown and facility emergencies, and to sustain reliable support for critical facilities and equipment [6:1].

The objective of RMP is therefore to maximize equipment life expectancy at a minimum cost.

The current RMP developed from a manual preventative maintenance program that was in use before the initiation of the Base Engineer Automated Management System (BEAMS) (to be discussed later). Under the manual system, a card file was kept for each item that was scheduled for preventative maintenance. As the inventory list grew, revision and up-dating of the card file became more difficult and the system slowly disintegrated (12). Automation has all but eliminated this problem. The present RMP can now be rapidly updated, revised, and reviewed as often as necessary.

An item is considered for entry into the recurring maintenance inventory if (17:10-1):

1. It is in the category of real property, real property installed equipment (RPIE), or other equipment maintained by the BCE organization (this research will be directed towards those items identified as RPIE).

2. The item has a replacement cost of $250 or less (this can be overruled if failure would have an impact on mission success).

3. The scope of work required is known without a prior visit to the job site.

4. Maintenance is performed at least once a year but not daily.

If an item meets the above criteria, it can then be established as an inventory item by the shop supervisor. Final approval for this item is made by the superintendent. The superintendent is also responsible for periodically reviewing the inventory list to insure that only essential items are retained. If it is determined that an item should not be entered into the program, that item can be submitted at a later date for reconsideration.

After an item is established as an inventory item, the maintenance requirements for that item must be formally identified. These requirements include the maintenance actions to be performed, the frequency at which the item is to be maintained, the man-hours required to perform the maintenance action, and any material that may be required (17:10-2). There are four sources from which this information is derived (17:10-2):

1. Manufacturer's recommendations.

2. Air Force manuals and regulations.

3. Experience of those responsible for the required maintenance.

4. Additional technical data.

This information is then used to prepare Air Force Form 1841, Maintenance Action Sheet (MAS).

The MAS is completed by the shop supervisor using the identified maintenance requirements. A MAS is prepared for each item in the recurring maintenance inventory (17:10-2). However, only one MAS is required for like items requiring identical maintenance actions, man-hours needed for accomplishment, and maintenance frequency. Two MAS's must be prepared for like items having identical maintenance actions, but different man-hours required for accomplishment. (This is true even though items may be maintained at the same frequency. Procedure requires that only one standard hour entry be made per frequency (17:10-2).) A situation of this type could develop if the ages of the like items differ, or locations differ such that more maintenance time is required. The completed MAS is reviewed by the superintendent who initials the form, notes any changes, and returns it to the shop supervisor (17:10-2). Once the MAS has been approved, workers use this form in identifying the tasks they will be responsible for completing. (A sample MAS is shown in Appendix A.)

The next phase in the cycle of a RMP item is scheduling. Each shop determines how many man-hours are required to complete the tasks identified. Air Force form 561 lists the tasks to be performed and the number of man-hours required to perform those tasks for a particular shop. A meeting is then held between the scheduler and the shop supervisor to divide the work requirements into daily packages (17:10-2). Once these packages have been formed, they are sent to production control where copies are reproduced. Printed schedules are then used by the controller for work assignments to the shops. After a job assignment has been made, the material requirements that are needed for a maintenance action must be available before the action can be performed. If material is required, and not available, maintenance is rescheduled.

Once on site, if the worker discovers that the item requires additional maintenance, the controller is notified. A decision is made as to whether the action can be performed based on the present day schedule, material availability, and the nature of the additional maintenance (17:10-3). If the task cannot be accomplished, the shop supervisor and superintendent are notified. This action will require the item to be rescheduled. Upon completion of the maintenance action, the controller is notified and a new task is assigned (17:10-3). (A graphical presentation of this process is shown in Figure 1-1.)

Once the maintenance action on an item is complete, the controller updates the appropriate completion card with actual man-hour data (17:10-3). The cards are then forwarded to data automation where the information is used in processing future RMP schedules. This completes the first cycle for an item requiring recurring maintenance.

The automated information system used by the BCE organization in organizing and processing recurring maintenance information is the Base Engineer Automated Management System (BEAMS). BEAMS is a performance reporting system that is used by BCE management in analyzing available resources and their allocation effectively and efficiently.

> The purpose of BEAMS is two-fold: (1) to provide information to BCE personnel to more efficiently and effectively manage resources, and (2) to provide, through minimum base effort, reports required by higher headquarters and the Congress [18:2-1].

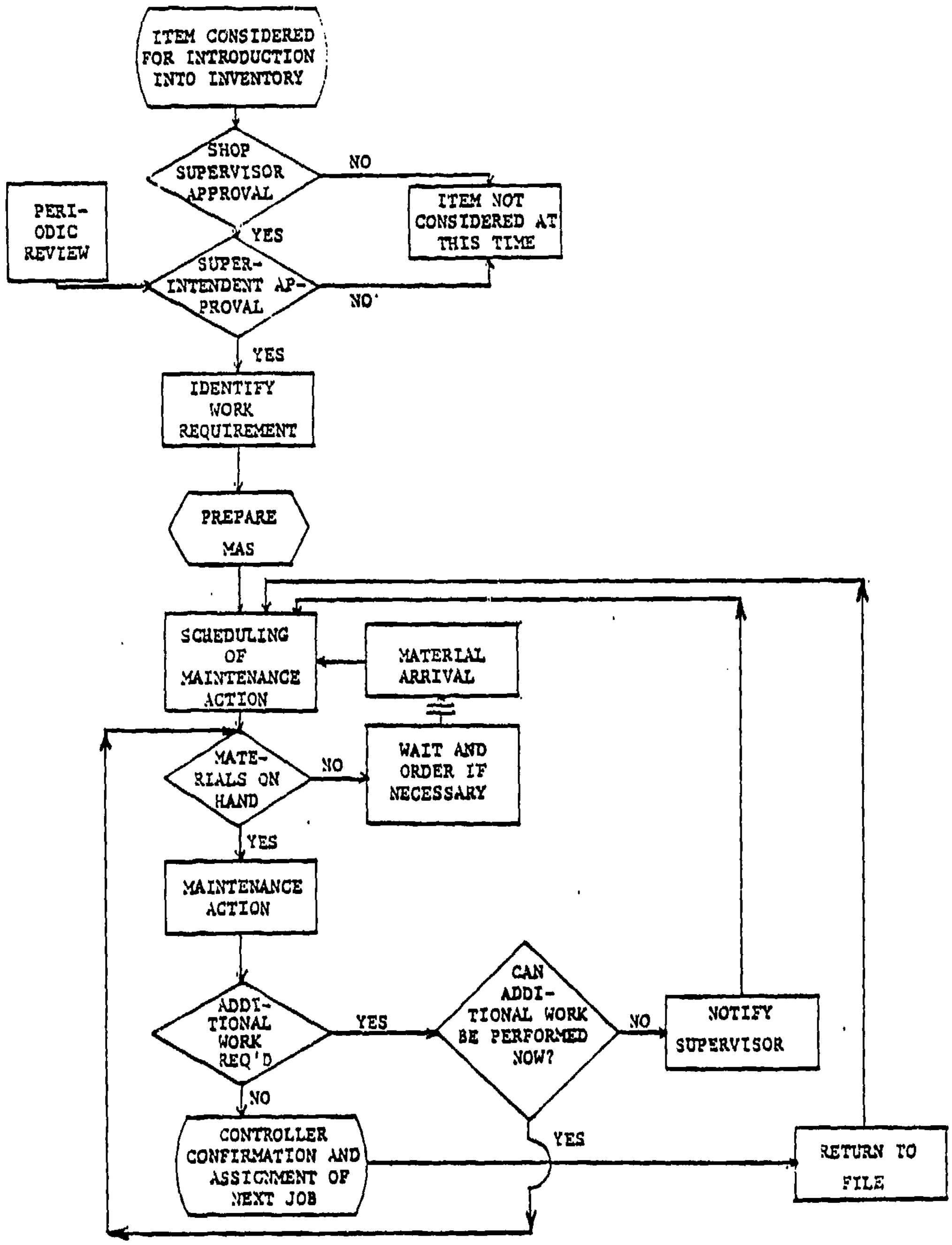


Fig. 1-1. Cycle of a Civil Engineering Recurring Maintenance Item

BEAMS has been described as the most comprehensive performance reporting system in the U.S. Air Force (8:70).

BEAMS consists of nine subsystems (see Appendix B); each subsystem contains a series of reports available to management for use in accessing the performance of Civil Engineering activities. Data from these activities are integrated by BEAMS into a common data base to assist in the reporting of accurate and consistent information (18:2-1). The RMP data is processed by a subsystem package contained in BEAMS.

The BEAMS RMP subsystem is designed to aid BCE management in scheduling maintenance actions for items contained in the recurring maintenance inventory (18:19-1). This is accomplished through a series of reports available within the RMP subsystem. (A list of these reports is shown in Table 1-1. If further information on these reports is desired, AFM 171-200, Vol. II, should be consulted.) In addition to the reports published within the BEAMS RMP subsystem, an executive management summary for the RMP is produced within the subsystem of Executive Management Summaries (see Appendix B). The purpose of this report is to provide data in capsule form to allow a rapid determination of program effectiveness. The automation provided by BEAMS aids in accomplishing the objective of RMP (maximize equipment life expectancy at a minimum cost) by tracking and identifying when maintenance for an inventory item is to be

Table 1-1

Reports Contained in the Civil Engineering RMP Subsystem

| Report Frequency | Product Title | PCN |
|---|---|---|
| WEEKLY | Recurring Maintenance Transaction List (Parts I & II) | SF100-130 |
| WEEKLY | Supplementary File Information | SF100-130 |
| WEEKLY | Recurring Maintenance Schedule (Parts I & II) | SF100-131 |
| WEEKLY | Recurring Maintenance Completion Cards | SF100-137 |
| AS-REQUIRED | Recurring Maintenance Man-hour Comparison Report | SF100-134 |
| AS-REQUIRED | Recurring Maintenance Deleted Items | SF100-133 |
| AS-REQUIRED | Type/Number Register | SF100-132 |
| AS-REQUIRED | Cost Comparison Report | SF100-135 |
| AS-REQUIRED | Recurring Maintenance Reserved Man-hours | SF100-688 |

performed (18:19-1). The BEAMS data file for the RMP also interfaces with the data files of Real Property, Labor, and Work Control to further increase the efficiency at which current management information is provided (18:19-1).

As the BEAMS RMP subsystem identifies those items requiring maintenance, a two-part schedule is produced. Part I consists of those items scheduled for maintenance during the current week and Part II consists of those items scheduled for maintenance the following week (18:20-53,54). Many times due to higher priority work requirements, maintenance work from the previous week is unable to be completed. These items appear as "overdo" in Part I and must be rescheduled. Incorporating "overdo" items into Part I at present is based on frequency, where frequency is defined as the repetitive interval at which maintenance is to be performed. All unaccomplished maintenance for a given week is reported to the controller for recording at the end of the schedule week. The information is then processed to update the previous week's Part II into a Part I to begin a new week. The current schedule, Part I, is then distributed to the respective shop supervisors for work accomplishment. Also, in the event a shop develops a backlog of urgent work, and man-hours are needed to accomplish that backlog; RMP then becomes a potential source from which these man-hours are made available. This is at the expense of not accomplishing the scheduled recurring maintenance work (12). This further complicates the process of maintenance action accomplishment between items as more "overdo" items appear on future week schedules.

The items listed in Part I for scheduled maintenance and those identified as "overdo" are reported in a form that does not identify or prioritize the relative importance of task accomplishment. Stated in a different way, the present system does not provide BCE management with a means of determining a single item's priority for maintenance accomplishment in relation to other RMP Part I items. In its current state of operation, the system is programmed to recognize those items listed as critical and noncritical (18:20-10). An item is defined as critical if the failure of that item would jeopardize the base mission. This determination is made by the shop supervisor on the basis of experience and knowledge of the inventory item in relation to the base mission (12). The listing of these items on the RMP Part I is random. No systematic order exists for printing these items on Part I. Critical items are only identified on the current schedule printout by a "yes" located under the column heading, Critical.

Due to recent changes made to AFR 85-1, the RMP now competes with other civil engineering job requirements for available man-hours (17:13-3). With the RMP no longer receiving "reserved man-hours" to accomplish assigned tasks, improvements in procedures must be made if the program is to effectively accomplish its objective (maximizing equipment life expectancy at a minimum cost). This research will be directed towards assisting management in the decision making process of selecting an inventory item for maintenance accomplishment by establishing a priority decision matrix. The priority decision matrix would operate under a systematic procedure by which all inventory items would be prioritized based on a set of determined decision factors. (Decision factors will be discussed in Chapter 2.) The prioritized list of RMP items would assist in reducing the apparent subjective decision making procedures now in the program, and provide management with a more objective basis to make a decision concerning the priority of accomplishment of the RMP tasks.

## JUSTIFICATION FOR RESEARCH EFFORT

Justification for this research effort is based on two areas: (1) recent changes to AFR 85-1, and (2) the data presentation of the BEAMS RMP subsystem output for Part I schedules.

Since the RMP now competes with other work requirements for available man-hours, the inability to reserve the necessary man-hours required by RMP may reduce the probability of meeting RMP's objective. This potential loss of reserved man-hours for recurring maintenance action will require the best possible utilization of those man-hours which the RMP is assigned. A priority matrix would assist management in making objective decisions concerning the accomplishment of a maintenance task on one inventory item before another.

The present output supplied by the BEAMS RMP subsystem for the Part I schedule does not provide the data in a useful format for decision making. The difficult transformation from data to information can be highlighted in two examples.

When the Part I schedule is published, the items are not reported in a form that identifies the importance or priority of task accomplishment of one item in relation to another. Also, items that are listed as "overdo" and critical, are reported at random throughout the schedule listing. This lack of prioritization could potentially lead to the accomplishment of lower priority tasks and ultimately effect the base's mission.

Another example is when a particular shop has scheduled work requirements for which additional man-hours are required, but are unavailable. Often, an area from which these man-hours are made available is the RMP. The reasoning behind this is that the work tasks in the RMP are recurring and a missed maintenance action will usually not endanger the base mission. However, when an item is pulled to compensate for the man-hour shift, the decision of which item to pull is based on the number of man-hours needed. This introduces the possibility of selecting an item, that if pulled would not represent the best choice of those items available for deletion. A decision of this type is now based on the experience and knowledge that the shop supervisor and scheduler possess about those items available for selection. A priority listing of the available inventory items would not only expedite the decision process, but also identify those items that would least likely adversely affect the base mission.

## STATEMENT OF THE PROBLEM

The Air Force Civil Engineering Recurring Maintenance Program,

> . . . provides for the automatic scheduling of required maintenance actions for Real Property Installed Equipment, Non-Real Property Installed Equipment and other identified recurring maintenance actions [18:2-5].

The strength of this program lies in its ability to automatically schedule items for work. This strength, however, is not without its weaknesses. Many times scheduling problems begin to develop as incomplete and unaccomplished jobs are reintroduced into the current work schedule. Specifically, the RMP fails to recognize high priority items of maintenance and the actual scheduling of these jobs. At the present time, no management tool exists to aid in the process of priority job recognition for scheduling. The goal of this research is to investigate the current operations of the RMP in order to develop a systematic procedure by which management will be able to recognize high priority jobs for task scheduling.

## OBJECTIVES

The objectives of this research are:

1. To identify those decision factors that will be used in determining the priority of maintenance action for RMP items.

2. To establish a systematic procedure based on the determined decision factors so that an item will be identified in relation to other items in the inventory as being of higher or lower priority in the performance of maintenance operations.

## RESEARCH QUESTIONS

1. Does there exist a general set of decision factors that may be applied to all RMP items in prioritizing maintenance tasks?

2. Can a systematic procedure using a general set of decision factors, be developed such that it will be flexible within a changing environment?

## Chapter 2

## METHODOLOGY

### DESIGN OF TEST

To test the research questions, interviews were conducted to determine those decision factors that are used in the priority rating of maintenance tasks. This data was collected from Dayton area organizations and Wright-Patterson Air Force Base. Selection of Dayton area organizations was made to incorporate functions that are parallel to those found in the Air Force.

The methodology was developed to utilize the decision factors in a systematic procedure to rank order maintenance accomplishment. The decision factors were used to establish a maintenance priority number for each maintenance item. The maintenance priority number is determined by first using a pairwise comparison procedure to establish the importance of the decision factors to the user shop. From the pairwise comparison, a decision factor weight was calculated and assigned to the respective decision factor. Inventory items can then be assigned utility values reflecting the importance of the decision factors on the accomplishment of a maintenance task. Upon completing this procedure, each item will have a computed maintenance priority number which may then be used to order maintenance tasks accomplishment.

## POPULATION AND SAMPLE

Data for this research was collected from two sources: organizations located in the Dayton, Ohio, area, and Wright-Patterson AFB. The selection of Dayton area organizations consisted of: (1) a manufacturing plant, (2) a hospital, (3) a university, and (4) an airport. The organizations used in this research were selected on the basis that they presently operate a preventative maintenance program. The four types of organizations selected perform maintenance functions and activities which parallel those found in the RMP of the BCE organization. This sample of the population of Dayton area organizations was a purposive judgment sample.

Data relating directly to the Air Force Civil Engineering RMP was collected from the 2750th Civil Engineering Squadron at Wright-Patterson AFB. The civil engineering (CE) squadron operates twenty-four work centers, of which eight operate recurring maintenance programs (12).

Wright-Patterson is a large base when compared to other Air Force installations located in the Continental United States (CONUS). This fact is highly visible when the diversity of missions resident to the base are considered (education, research and development, flying). The extent of the RMP in operation at Wright-Patterson is reflected in the 1978 fiscal year use of man-hours (81,771) and dollars spent ($858,950) on its RMP alone (12). Every Air Force base is required under Air Force directives to maintain a RMP. However, some degree of freedom does exist in the operation of a RMP at base level. This flexibility allows a base to establish a program tailored to its specified mission.

The RMP currently operating at Wright-Patterson may or may not be involved in the same missions as other RMPs functioning at other Air Force bases. Different priorities between bases may also exist. A difference in the decision factors used in determining priority accomplishment of RMP tasks, however, should not exist.

## DATA COLLECTION PLAN

The data for this research was collected by personal interviews with maintenance personnel at the decision making level responsible for recurring maintenance. From the Civil Engineering Squadron at Wright-Patterson AFB, seven shop supervisors responsible for their shop's operation of the RMP were interviewed. These shops were:

Metal
Interior Electric
Exterior Electric
Hospital Maintenance

Plumbing

Steamfitters

Air Conditioning & Refrigeration

The POL shop (petroleum oil lubrication) was excluded as it did not contain a sufficient number of RMP items.

In the civilian sector, four supervisory personnel responsible for the recurring maintenance of their organization were interviewed. These organizations were:

Dayton International Airport

Wright State University

Miami Valley Hospital

Delco Products Division

These organizations were selected on the basis that they presently operate a preventative maintenance program similar in functions and activities to those found in the RMP of the BCE organization.

These interviews were conducted to obtain the decision factors that these individuals use in the thought process applied in determining the priority attached to equipment on which preventative maintenance is performed. The interviews were open and respondents were allowed to answer the questions freely and to the extent they felt was necessary. The purpose of providing this freedom was to avoid any intentional bias from being introduced into the interview. Examples of the questions asked during the interviews are located in Appendix C.

The operational definition of a decision factor is one that, if not considered in the process of priority scheduling of maintenance items, could adversely affect the mission of an organization or facility by an unexpected breakdown of essential equipment or cause extensive and costly damage to a piece of equipment. By interviewing various CE shops and civilian organizations, a collection of decision factors was obtained such that the needs and missions of the respective shops and organizations would be represented. The purpose of this collection plan was for those interviewed to identify those decision factors they felt were important in the prioritization of maintenance items for task accomplishment. From this pool, a required list of decision factors could be developed so that those decision factors shared by these environments could be used in a systematic procedure to determine the priority of a given maintenance item.

## SYSTEMATIC PROCEDURE

Once the decision factors have been identified, a systematic procedure was developed to prioritize the maintenance items. An important objective in the development of this procedure was to build in flexibility so that it could be tailored to the specific needs and mission of the user shop. The systematic procedure then provides a method to objectively rank maintenance items in a relative priority listing for accomplishment. Each shop will use the required list of decision factors in the priority determination. The shop, however, is not limited to the required list of decision factors. Additional factors are suggested and the shop is also free to use any additional factors that it feels would enhance the performance of the procedure.

By using a pairwise comparison procedure, each of the decision factors to be used in the procedure will be assigned a weight which will denote the relative importance of the decision factor to the respective shop. These decision factor weights will vary from shop to shop. Once the weight parameter has been established, the item by item ranking process can begin. It is important to note that the pairwise comparison procedure will only have to be accomplished once by each shop for their RMP.

A utility value for each decision factor used in the pairwise comparison is then assigned for each maintenance item. This utility value will correspond to the relative importance of that decision factor to the accomplishment of the maintenance task. The outcome of this process is that each item in the RMP will possess an intermediate priority value for each decision factor based on the expertise and judgment of shop personnel responsible for the RMP.

Once this process is completed, a maintenance priority number can be computed for each item. This number is used in prioritizing the inventory of RMP items. Job priority is established by sequential ordering of the maintenance priority numbers in a descending manner. In the event of a tie between two items having the same priority, the selection would be arbitrary. Therefore, by use of a simple sorting process, priority for job accomplishment may be established. This prioritized list of maintenance items can then be used for effective scheduling.

The subject of unaccomplished work is also addressed in this procedure. Unaccomplished work in the Air Force Civil Engineering environment represents an area of great concern because of the backlog of work which it causes. The problem of unaccomplished work will be handled by this procedure in such a way that a factor will be multiplied to the maintenance priority number, thereby increasing the value for the next scheduling cycle. This value increase will cause the item to be placed higher in the priority list increasing the probability of accomplishment. If an item is continually missed, the factor will continue to be applied drawing additional attention to the fact that it has not been accomplished.

## A SUMMARY LIST OF ASSUMPTIONS

1. Items on a preventative maintenance program are cost effective to maintain and breakdown probability can be accurately predicted.

2. A general list of decision factors can be applied to all items requiring preventative maintenance.

A SUMMARY LIST OF LIMITATIONS

1. All non-Air Force organizations were restricted to those established in the Dayton, Ohio, area.

# Chapter 3

## DATA ANALYSIS

The objective of the data collection plan was to identify those decision factors used by maintenance personnel in the prioritization of preventative maintenance activities (research question 1). These decision factors represent a mental checklist that is used by maintenance personnel to determine a preventative maintenance item's importance in relation to other items contained in the preventative maintenance inventory. Experience and equipment familiarization are key factors in the development of these decision factors. Used during daily job activities, these factors have become intuitive to the work of maintenance personnel.

The decision factors identified during the respective interviews with maintenance personnel are presented in Tables 3-1 and 3-2 (3; 4; 5; 7; 9; 10; 11; 13; 15; 16; 19; 20). Table 3-3 illustrates the total number of decision factors identified, the number of times they were identified, and by whom they were identified. These tables do not reflect the importance which is placed on these factors or are these factors listed in any intended order.

There was general agreement on many of the decision factors used in prioritizing maintenance performed on one

Table 3-1

**Decision Factors Derived From Personal Interviews With 2750th Civil Engineering Squadron Shop Supervisors By Shop**

| Metals | Interior Electric | Exterior Electric | Hospital Maintenance | Plumbers | Steamfitters | Air conditioning & Refrigeration |
|---|---|---|---|---|---|---|
| 1. Material | 1. Location | 1. Seasonality | 1. Equipment type | 1. Frequency | 1. Equipment type | 1. Seasonality |
| 2. Location | 2. Equipment | 2. Equipment purpose | 2. Equipment dependence | 2. Equipment type | 2. Equipment dependence | 2. Past data |
| 3. Frequency | 3. Past data | 3. Equipment type | 3. Equipment purpose | 3. Manpower | 3. Manpower | 3. Location |
| 4. Employee observation | 4. Regulations | 4. Equipment dependence | 4. Seasonality | 4. Seasonality | 4. Location | 4. Equipment dependence |
| 5. Manpower | | 5. Employee observation | 5. Frequency | 5. Equipment dependence | 5. Frequency | |
| 6. Amount of use | | 6. Manpower | 6. Manpower | 6. Employee observation | 6. Employee observation | |
| 7. Frequency of use | | 7. Frequency | 7. Frequency of use | 7. Amount of use | 7. Seasonality | |
| 8. Manufacture's recommendations | | 8. Equipment cost | 8. Amount of use | 8. Location | | |
| 9. Equipment type | | 9. Amount of use | 9. Employee observation | | | |
| 10. Equipment dependence | | 10. Location | 10. Location | | | |
| 11. Facility function | | 11. Age | | | | |

Table 3-2

Decision Factors Derived From Personal Interviews With Dayton Area Organizations

| Miami Valley Hospital | Delco Products Division | Wright State University | Dayton International Airport |
|---|---|---|---|
| 1. Safety | 1. Dependence | 1. Employee observation | 1. Employee competence |
| 2. Seasonality | 2. Past data | 2. Manpower | 2. Past data |
| 3. Manpower | 3. Cost of downtime | 3. Equipment purpose | 3. Cost |
| 4. Equipment purpose | 4. Safety | 4. Equipment dependence | 4. Employee observation |
| 5. By-law standards | 5. Equipment purpose | | 5. Seasonality |
| 6. Equipment dependence | 6. Equipment type | | 6. Frequency of use |
| 7. Equipment type | 7. Seasonality | | 7. Amount of use |
| | 8. Manufacturer's recommendations | | 8. Age |
| | | | 9. Equipment purpose |
| | | | 10. Manufacturer's recommendations |

Table 3-3

Decision Factor Breakout

| Decision Factors | Interviews | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Metal Shop | Interior Electric | Exterior Electric | Hospital Maintenance | Plumbing Shop | Steamfitters Shop | Airconditioning & Refrig | Miami Valley Hospital | Delco Products Division | Wright State University | Dayton International Airport |
| Material (1) | ✓ | | | | | | | | | | |
| Location (7) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | |
| Maintenance Frequency (5) | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | | |
| Employee Observation (7) | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ |
| Manpower (7) | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | |
| Amount of Use (5) | ✓ | | ✓ | ✓ | ✓ | | | | | | ✓ |
| Frequency of Use (3) | ✓ | | | ✓ | | | | | | | ✓ |
| Manufacturer's Recommendation (3) | ✓ | | | | | | | | ✓ | | ✓ |
| Equipment Type (7) | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | |
| Equipment Dependence (9) | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Facility Function (1) | ✓ | | | | | | | | | | |
| Equipment Purpose (7) | | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ |
| Seasonality (8) | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Equipment Cost (plus downtime cost) (3) | | | ✓ | | | | | | ✓ | | ✓ |
| Equipment Age (2) | | | ✓ | | | | | | | | ✓ |

Table 3-3 (continued)

| Decision Factors | Interviews | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Metal Shop | Interior Electric | Exterior Electric | Hospital Maintenance | Plumbing Shop | Steamfitters Shop | Airconditioning & Refrig | Miami Valley Hospital | Delco Products Division | Wright State University | Dayton International Airport |
| Past Data (4) | | ✓ | | | | | ✓ | | ✓ | | ✓ |
| Safety (2) | | | | | | | | ✓ | ✓ | | |
| Employee Competence (1) | | | | | | | | ✓ | | | |
| Regulations (2) | | ✓ | | | | | | ✓ | | | |

item over another. Although many shops identified the same decision factors, there existed expressed differences as to the emphasis placed on the use of those factors. For example, the steamfitters shop emphasized location as an important factor due to transportation difficulties. Hospital maintenance, however, cited location as a minor consideration in the decision process. All RMP items for the Hospital Maintenance shop are located in the same facility, eliminating or decreasing the importance of location as a decision factor. Instead of location, Hospital Maintenance stressed equipment dependence as an important decision factor. Also, some shops identified certain decision factors that were not considered by other shops. An example of this is the decision factor of equipment cost identified by the Exterior Electric shop due to the very high replacement cost of the equipment. Cost was also addressed by Dayton organizations. However, there exists a different philosophy of operation between the public and private sectors when addressing the aspect of cost (this difference does not make the use of equipment cost any less valid). The difference in decision factor emphasis is accounted for by weighting the decision factors in accordance with the user shop's requirements.

In total, nineteen decision factors were identified by the eleven maintenance personnel interviewed. A procedure has been designed to identify those items having a higher priority for accomplishment and to establish a ranking by which these items would obtain precedence over lower ranking items. A procedural update would only need to be accomplished after a significant change to an item's priority status (e.g., a major overhaul). However, not all of the factors identified are applicable to the systematic procedure to be used in the prioritization of preventative maintenance items. Of the nineteen factors identified, manpower, employee observation, employee competence, and manufacturer's recommendation fall into this category.

Although manpower was identified by many of the maintenance personnel interviewed, it is a real time factor to be used in daily or weekly scheduling. The definition of a real time factor is a factor whose input can not be acted upon in time to influence the outcome of the established procedure. The identified decision factors must be used to determine a priority rating of preventative maintenance requirements and thereby establish a priority for accomplishment. This will allow the most critical maintenance actions to be performed within given manpower constraints. Since manpower is a fluctuating real time factor, its use for the purpose of this research is not applicable.

An example to illustrate how the priority rating is used in conjunction with manpower is as follows. Given a finite number of man-hours to accomplish a set of activities, the prioritized list of maintenance items could be used to identify those items that are essential to accomplish within the man-hour constraint. This is not to suggest that those items not selected should be neglected or removed from consideration. However, these items may justifiably be placed aside to be accomplished at a later date. These items would be "overdo" and will be multiplied by a factor to increase their priority.

Another factor that was not considered applicable to this research is employee observation. Employee observation as a factor is reactive in nature and not a preplanned occurrence. That is, an employee may identify a potential problem or a need for immediate maintenance during the course of a daily job routine. This type of factor is applicable to a real time situation. Therefore, although identified by many of the maintenance personnel interviewed, it is unsuitable for the purpose of this research. However, it should be recognized as a valuable resource which may effectively enhance a shop's operation.

Another factor which was discarded is employee competence. It was assumed that all employees involved in the performance of preventative maintenance are adequately trained and fully competent to accomplish the maintenance tasks required.

The final factor to be eliminated is manufacturer's recommendation. One of the sources used in establishing the initial requirements for a maintenance item were the manufacturer's recommendations. Since this would represent a duplication of effort, it will not be used in this research.

Two additional factors will not be used: equipment purpose and facility function. These factors are not inappropriate for use, but have been determined to be similar in meaning to another decision factor. For use in this research, equipment type and equipment purpose will be considered synonymous. Since there exists only a fine line of distinction between these two factors, the decision factor of equipment type will be used as defined in Appendix D. Facility function and equipment dependence will also be considered synonymous. Here, equipment dependence will be used as defined in Appendix D. The purpose of condensing is to aid in the clarification of decision factor definition.

During the initial investigative phase of this research effort, a statistical test (Binomial Test for Population Proportion) was to be used to identify those decision factors most often identified during the interviews. However, after completing the data collection process, it is felt that the use of such a statistical test would most likely eliminate a decision factor that a specific shop might consider important (e.g., equipment cost identified by exterior electric). Therefore, all the decision factors obtained through the interviews, with the exception of those previously eliminated are listed in Table 3-4.

Table 3-4

Identified Decision Factors

| Required List | Optional List |
|---|---|
| Location | Material |
| Maintenance frequency | Equipment cost |
| Amount of use | Equipment age |
| Frequency of use | Past data |
| Equipment type | Safety |
| Equipment dependence | Regulations |
| Seasonality | |

As a guide in selecting the decision factors to use, the factors illustrated in Table 3-4 have been split into two categories; a required list, and an optional list. The required list identifies those factors that are most likely to increase the probability of obtaining a valid priority rating when used in the priority establishing procedure. The optional list includes those factors which are available for use but should be selected on the basis of the user shop's requirements. This list should not be viewed as a complete list of factors that are used by maintenance personnel in the priority selection process. However, it can be considered as a base from which other factors may evolve according to the specific requirements of the user shop. Formal definition for the decision factors listed in Table 3-4 are located in Appendix D.

## PRIORITIZATION PROCEDURE

The development of the systematic procedure for the prioritization of preventative maintenance items required the elements of simplicity of theory and accuracy in operation (research objective 2). The element of simplicity was required so that personnel using the procedure would not become confused, frustrated, and eventually disinterested with the procedure consequently leading to failure. In a no lesser role, accuracy in practical operation was also sought. The systematic procedure has no value if it does not provide the results desired. In this framework, the systematic procedure developed for the prioritization of maintenance items was built.

The systematic procedure can be appreciated by a short summary of the overall process. The shop supervisor in addition to the required set can select optional decision factors which are applicable to his shop. The weighting of the required and optional decision factors is determined through the application of a pairwise comparison procedure (see Figure 3-1). Each item in the maintenance inventory is analyzed against all decision factors and assigned a utility value between 1 and 7. This value is then multiplied by the decision factor weight established previously. These intermediate priority values are then added together to give the

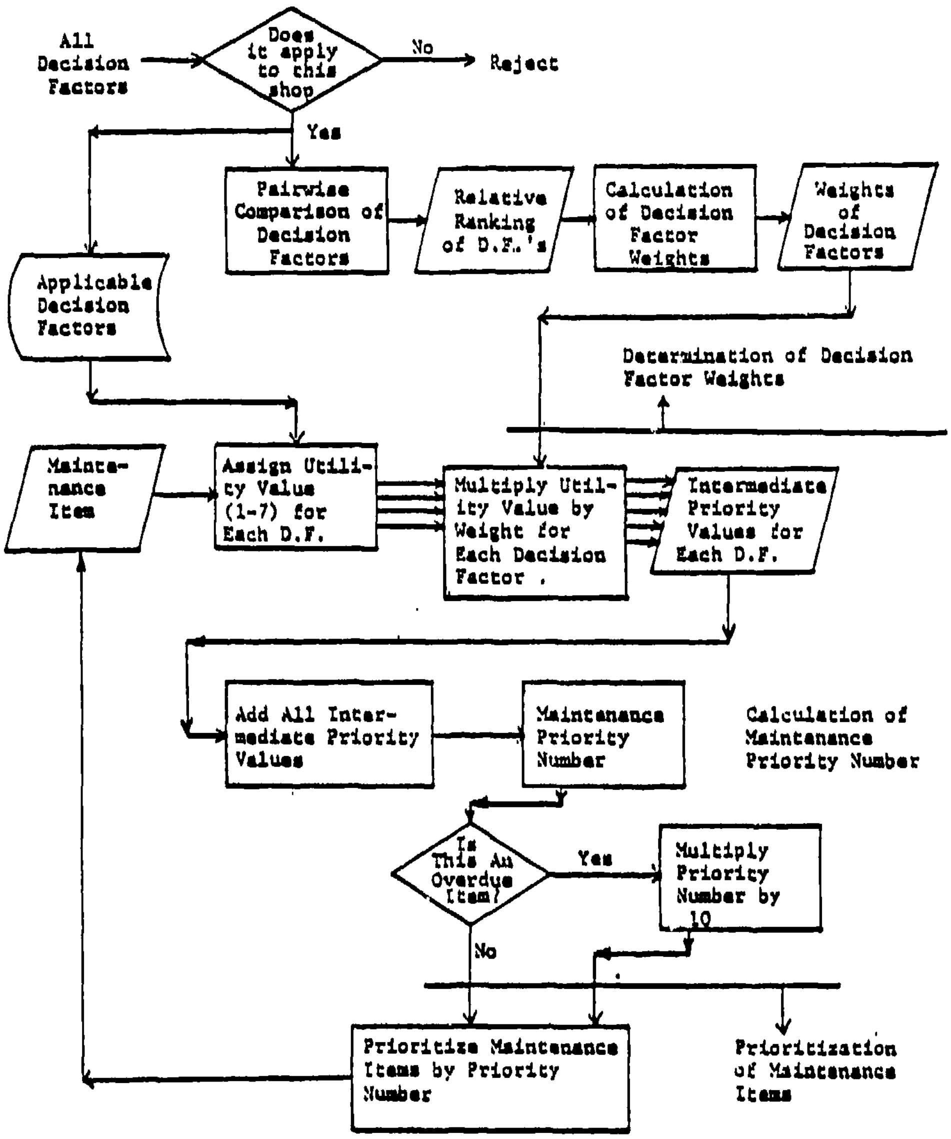


Fig. 3-1. Flowchart of Systematic Procedure

maintenance priority number. Finally, the maintenance items are sorted by maintenance priority number to yield a list of prioritized maintenance items.

In general, the systematic procedure can be divided into three steps: the determination of decision factor weights; the calculation of the maintenance priority number; and the prioritization of maintenance items. Each step will now be fully addressed.

### Determination of Decision Factor Weights

The decision factor weight determination is the most crucial step of the systematic procedure and must be done carefully. This requirement will not create a major workload to the shop supervisor or foreman because it must be done only once. The weight determination is achieved by means of a pairwise comparison of decision factors.

Prior to the pairwise comparison, supervisory personnel must carefully review the required and optional decision factor list provided. Each optional decision factor listed must be analyzed in light of the operation of the respective shop. Air Force directives, experience, mission objectives, and previous work encounters must all be taken into consideration in the analysis. Through this process, optional decision factors having a direct or indirect influence in preventative maintenance item prioritization will be selected. Any additional decision factors important to the particular shop in the prioritization of maintenance items should be added.

Pairwise comparison. Once the selection of the important optional decision factors has been completed, the pairwise comparison chart developed by Souder is used as a method to establish decision factor importance to the user. It provides, quite accurately, the relative rankings of the decision factors. The mechanics of the pairwise comparison require the construction of an n x n matrix, where n is the total number of decision factors. The applicable decision factors are listed as column and row headings on the matrix as shown in Figure 3-2A. In a systematic order, all column headings are compared with each row heading so that all pairs of decision factors are compared. When a column heading is determined to be more important than a row heading, a "+" is placed in the square of the matrix where the row and column intersect (see Figure 3-2B; B is more important than A). If a column decision factor is determined to be less important than a row decision factor, a "0" is placed in the square intersection (see Figure 3-2C; C is less important than A). This procedure is carried out for the entire matrix.

After all paired comparisons are completed, the column marginal totals of the "+"s and the row marginal totals of the "0"s are obtained. The column marginal totals having the highest number of "+"s is given a rank of "1", the next highest is given a rank of "2", etc., until all of the column decision factors have been ranked (14:670) (see Figure 3-2A).

Two possible problems can occur in the use of the paired comparison chart. These are circularities and intransitivities (14:670). Circularities occur when the column marginal totals of "+"s are unequal to the row marginal totals of "0"s for each respective criterion. In this case, the sequence of row and column marginal totals will not be the same. If, for example, in Figure 3-2A, the column D and row A intersection were a "+" rather than a "0", the marginal totals would differ in sequence as would the summation of marginal totals differ (see Figure 3-2D).

An intransitivity, on the other hand, is the occurrence of marginal totals, either row or column, having the same number of "+"s or "0"s. As an example using Figure 3-2A, if the column F and row E intersection were a "0" rather than a "+", the two marginal columns would contain two decision factors having the same totals. The decision factors E and F would have row marginal totals of 4 and column marginal totals of 3 (see Figure 3-2E).

In the case of an intransitivity or a circularity, the conflict must be resolved in order to proceed with the rank order. Resolution can be achieved by analyzing the chart to locate the inconsistency or by reworking the entire pairwise comparison matrix. Normally, analysis will uncover

| | A | B | C | D | E | F | Marginal Totals $\Sigma 0$'s |
|---|---|---|---|---|---|---|---|
| A | | 0 | + | 0 | + | + | 2 |
| B | + | | + | 0 | + | + | 1 |
| C | 0 | 0 | | 0 | 0 | 0 | 5 |
| D | + | + | + | | + | + | 0 |
| E | 0 | 0 | + | 0 | | + | 3 |
| F | 0 | 0 | + | 0 | 0 | | 4 |
| Marginal Totals $\Sigma +$'s | 2 | 1 | 5 | 0 | 3 | 4 | 15 15 |
| RANK | 4 | 5 | 1 | 6 | 3 | 2 | |

Fig. 3-2A. Example Pairwise Comparison

| | A | B | C | D |
|---|---|---|---|---|
| A | | + | | |
| B | | | | |
| C | | | | |
| D | | | | |

Fig. 3-2B. Example Pairwise Comparison

| | A | B | C | D |
|---|---|---|---|---|
| A | | | 0 | |
| B | | | | |
| C | | | | |
| D | | | | |

Fig. 3-2C. Example Pairwise Comparison

| | A | B | C | D | E | F | Σ 0's |
|---|---|---|---|---|---|---|---|
| A | X | 0 | + | + | + | + | 1 |
| B | + | X | + | 0 | + | + | 1 |
| C | 0 | 0 | X | 0 | 0 | 0 | 5 |
| D | + | + | + | X | + | + | 0 |
| E | 0 | 0 | + | 0 | X | + | 3 |
| F | 0 | 0 | + | 0 | 0 | X | 4 |
| Σ+'s | 2 | 1 | 5 | 1 | 3 | 4 | 14<br>16 |

Σ Marginal Totals

Fig. 3-2D. Example Pairwise Comparison

| | A | B | C | D | E | F | Σ0's |
|---|---|---|---|---|---|---|---|
| A | X | 0 | + | 0 | + | + | 2 |
| B | + | X | + | 0 | + | + | 1 |
| C | 0 | 0 | X | 0 | | 0 | 5 |
| D | + | + | + | X | + | + | 0 |
| E | 0 | 0 | + | 0 | X | 0 | 4 |
| F | 0 | 0 | + | 0 | 0 | X | 4 |
| Σ+'s | 2 | 1 | 5 | 0 | 3 | 3 | 16<br>14 |

Σ Marginal Totals

Fig. 3-2E. Example Pairwise Comparison

the inconsistency faster than by reworking the entire matrix. For example, in Figure 3-2E, decision factor E was judged to be less important than decision factor F. In the same sense, decision factor F was judged to be less important than decision factor E. This conflict, once identified, can be easily corrected since one decision factor must be more important than the other.

Decision factor weights. Once the pairwise comparison and the ranking of the applicable decision factors is determined, the decision factor weights are computed. Decision factor weights are calculated by the rank total being divided by the rank number. Thus, from Figure 3-2E, the rank total becomes:

$$1 + 2 + 3 + 4 + 5 + 6 = 21$$

The relative decision factor weights are then:

| Decision Factor | Rank Number | Decision Factor Weight |
|---|---|---|
| A | 4 | 21/4 = 5.25 |
| B | 5 | 21/5 = 4.2 |
| C | 1 | 21/1 = 21 |
| D | 6 | 21/6 = 3.5 |
| E | 3 | 21/3 = 7 |
| F | 2 | 21/2 = 10.5 |

It is evident the more important a decision factor becomes, the more relative weight it gains. Figure 3-3 graphically illustrates the relative weights for decision

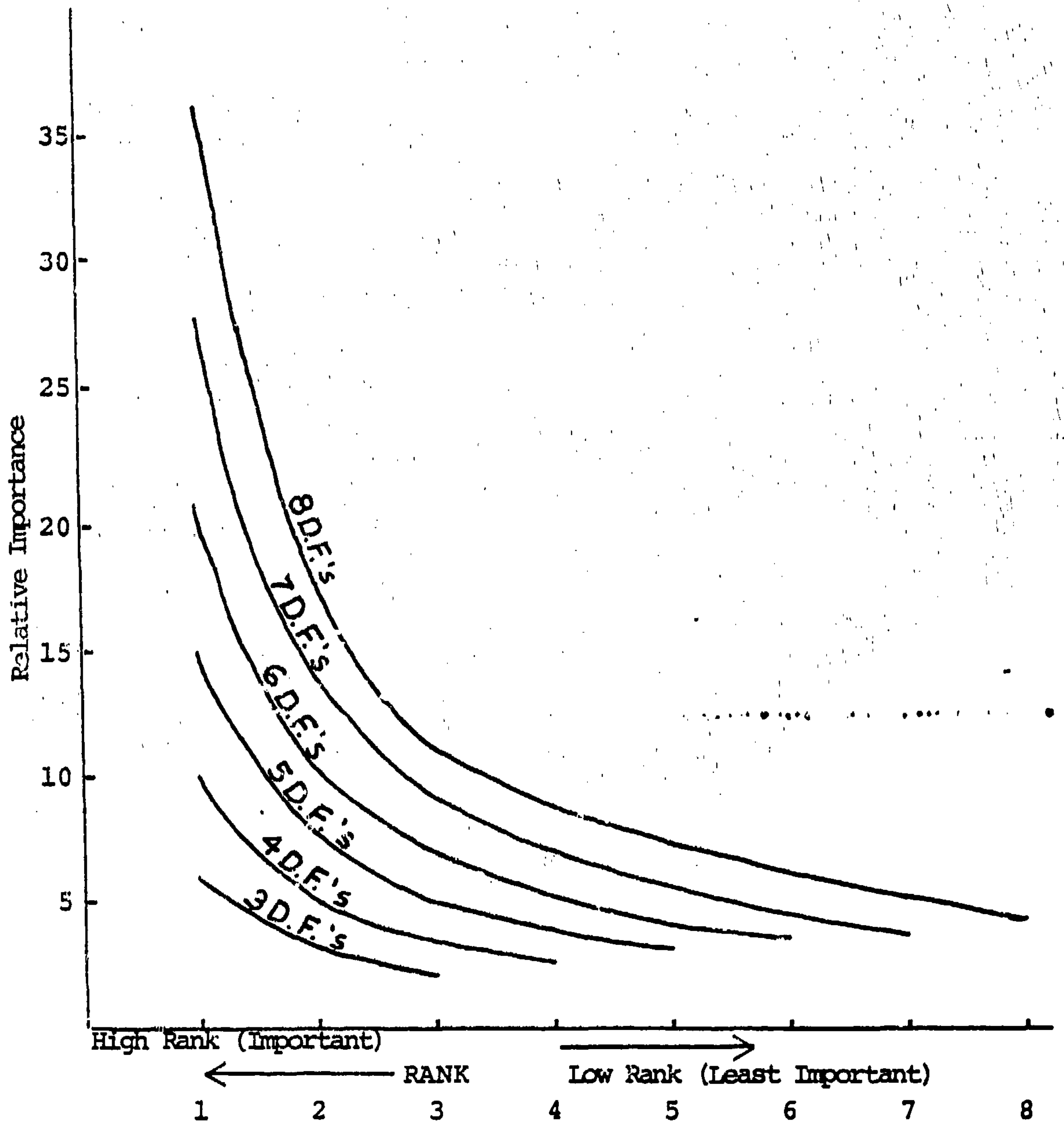


Fig. 3-3. Rank Order vs Decision Factor Weighting

factors for a number of decision factors used in the pair-wise comparison. The graphs trace exponential curves indicating that as a decision factor becomes more important, the more relative weight it obtains. For example, decision factors C and F are ranked 1 and 2 and have relative decision factor weights of 21 and 10.5, respectively. Decision factors B and D, ranked 5 and 6, have relative decision factor weights of 4.2 and 3.5, respectively. Another important point should be noted from the graph regarding the number of decision factors and their weights. That is, as the number of decision factors decreases so does their relative decision factor weights; but the weight range of these decision factors also decreases. If three decision factors are applicable to a shop, then the relative weights of the factors are 6 - 3 - 2. Comparing the weight range differences of the two highest ranking decision factors for a six and three decision factor case, the results are 10.5 and 3. This difference signifies the increasing importance of the number one ranked decision factor as the total number of decision factors used increases.

Calculation of Maintenance Priority Number

The calculation of the maintenance priority number is a step which utilizes the decision factors and their weights found in the previous step. Here, every item in the maintenance item inventory is compared against the decision factors in such a way to determine how much a particular decision factor applies to that specific maintenance item.

Utility values. As a means to determine how much or how little a decision factor applies to a particular maintenance item, a scoring model is utilized. This approach was selected for three important reasons. First, the scoring model is designed to use noneconomic based, subjective inputs. Since the use of economic data is virtually impossible for recurring maintenance due to the age of some equipment, prioritization by economic indices is not considered to be useful. Second, scoring models can operate on estimates by knowledgeable people familiar with recurring maintenance. Scoring models do not require precise data for input means, nor is any statistical instrument needed to determine input data (2:212-214). Third, the scoring model is easy to understand and easy to use. Of course, the above reasons are predicated on the assumption that the shop supervisor or shop foreman has adequate knowledge of his shop and its operations. This was found to be the case in all shops researched in this study.

The application of the scoring model follows the determination of decision factor weights. At this point, each maintenance item is compared, one at a time, to all the applicable decision factors for a shop. To each decision factor, the question is asked, "To what degree does this decision factor apply in determining this item's required maintenance?" The answer, being very subjective, is selected by estimating, on a scale of one to seven, the degree of relevancy the decision factor has in terms of a particular maintenance item (see Figure 3-4).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Never | | | Sometimes | | | Always |

Fig. 3-4. The Seven Interval Relevancy Scale

Seven intervals were selected for this scale for two reasons based on the study by Moore and Baker (2:212-232). First, seven intervals provide a sufficient range of choice. Nine intervals may tend to produce proximity error, strictness error, or leniency error due to the wide range of choice. A five interval scale, on the other hand, because of its narrower range of choice, could produce central tendency of the majority of estimates. Second, seven intervals was felt to offer more discriminatory power than the five or nine interval scales.

When each utility value has been selected for each decision factor, an intermediate priority value for each decision factor can then be calculated. This intermediate priority is obtained by multiplying the utility value by the decision factor weight for each decision factor. The intermediate values, by themselves, offer no real meaning to the overall prioritization. They are only the inputs to the final phase of this step.

<u>Maintenance priority numbers</u>. The maintenance priority number is the additive total of all the intermediate priority values for the maintenance item. The number is dimensionless and establishes a comparative priority of the maintenance item to all other items.

Two possible means were available for the calculation of the maintenance item priority number: by addition and by multiplication. The additive model was selected over the multiplicative model for three reasons. First, the additive model of scoring results in higher consistency of rating order over the multiplicative and the economic index mo[illegible]sted (2:220). Second, the multiplicative model te[illegible]e high priority to items that receive an "average[illegible] on all of the decision factors rated (2:220). [illegible], the use of a multiplicative model for scoring results in maintenance priority numbers which are large and difficult to use and cumbersome to manipulate. The additive model provides priority numbers that are more consistent, eliminates grouping, and is easier to use in this procedure.

<u>Overdue items</u>. Overdue items in the maintenance inventory pose no special problems to this systematic procedure. Since a missed maintenance cycle should place an added

importance of the item in relation to the rest, a means must be built into the systematic procedure to adequately account for the item. In view of this added importance of an overdue item, recognition of the high priority can be achieved quite simply. This is gained by taking the maintenance priority number computed in the previous step and multiplying it by a factor of ten. This will essentially force the particular item to gain a high priority number thus insuring that it will take precedence over the remaining items.

### Prioritization of Maintenance Items

When the maintenance priority numbers for all of the maintenance items have been calculated, prioritization of the maintenance items can be achieved. This procedure entails the process of sorting the items by priority number. The highest priority item is the item having the highest priority number while the lowest priority item is that which has the lowest priority number. The outcome is a list, in order of priority importance, which will identify at a glance the maintenance items to be considered for man-hour allocation.

The possibility of two or more maintenance items having the same priority number poses no immediate problem. In such a case, the expertise of the maintenance personnel would be utilized to select the order in which maintenance is to be performed. If expertise is not available, the arbitrary appointment of order is sufficient to insure the integrity of the systematic procedure. A complete illustrative example of this procedure is located in Appendix E.

## Chapter 4

## SUMMARY, CONCLUSION, AND FUTURE RESEARCH

### SUMMARY

The objectives of this research were twofold:

1. To identify those decision factors that will be used in determining the priority of maintenance action for RMP items.

2. To establish a systematic procedure based on the determined decision factors so that an item will be identified in relation to other items in the inventory as being of higher or lower priority in the performance of maintenance operations.

This research concentrated on identifying those decision factors used by maintenance personnel to aid in the prioritization of preventative maintenance items. Also, the development of a priority decision matrix by which maintenance items can be ranked according to the importance placed on the required maintenance action.

The decision factors were collected through personal interviews conducted with maintenance personnel responsible for preventative maintenance in their shops or organizations. The identified decision factors were broken down into two categories--required and optional. The required set represents those decision factors that are common to all preventative maintenance activities. The optional set contains those decision factors which were prevalent but not all encompassing. However, these factors were identified often enough to be included so that a user may, in addition to the required set, add an optional factor if it will enhance the validity of the procedure.

The required set of decision factors will be used in a two part procedure as a means of prioritizing RMP items in relation to one another. Part one consists of a pairwise comparison which attaches a weight to each required decision factor indicating the importance of the decision factor to the user shop. In part two, a utility value is assigned to each decision factor on an item by item basis. The maintenance priority number is calculated from the product of the utility value and weight of the corresponding decision factor. This product represents an intermediate priority value, the intermediate priority values for each decision factor are summed to yield the maintenance priority number.

Once all RMP inventory items have been processed (assigned a maintenance priority number), a prioritized list can then be established to aid management in effective scheduling. A complete illustration of this procedure is located in Appendix E.

## CONCLUSION

This research addressed two questions:

1. Does there exist a general set of decision factors that may be applied to all RMP items in prioritizing maintenance tasks?

2. Can a systematic procedure, using a general set of decision factors, be developed such that it will be flexible within a changing environment?

Research has provided positive answers to both of these questions.

Through interviews with maintenance personnel, a total of nineteen factors were identified. However, four factors were eliminated due to their inability to add any significant information to the process of prioritization. Two additional factors were condensed into other factors which were synonymous. There are seven decision factors which make up the required set which will be used in the process of prioritizing RMP items. These are:

Location
Maintenance frequency
Frequency of use
Equipment type
Equipment dependence
Seasonality
Amount of use

(Formal definitions of these decision factors are located in Appendix D.) Five additional factors have been listed as optional (see Table 3-4). These optional decision factors are to be used in addition to the required set if they will improve the validity of the maintenance priority number. If applicable, additional factors may also be used when they are unique to the user to further supplement the required set. Therefore, on the basis of this research, the answer to research question one is positive: there does exist a general set (required set) of decision factors that will be applied to all RMP items in prioritizing maintenance tasks.

The systematic procedure incorporating these decision factors was developed in two parts. Part one established weight factors for each decision factor; part two completed the procedure by assigning a maintenance priority number to each inventory item. Part one of this procedure (pairwise comparison) builds in the required flexibility by allowing each shop to determine the relative importance of each decision factor. The incorporation of flexibility into the procedure is a key element for successful application to preventative maintenance programs regardless of the user mission. For Air Force wide implementation, flexibility is needed to attain uniformity of the RMP operation regardless of geographic location and mission. This procedure uses the required set of decision factors and through part one builds in the flexibility that is required for implementation into any preventative maintenance program. Therefore, the answer to research question two is positive.

Also addressed by this procedure is the overdo or unaccomplished maintenance item. If an item is scheduled for maintenance and the maintenance action is unaccomplished, the maintenance priority number will be multiplied by a factor of 10. This increase in the maintenance priority number will increase the item's priority rating against other inventory items. The factor of 10 was selected so that the priority would increase by a substantial degree. In most cases, multiplication by this factor will reestablish an overdo near the top of the priority rating. This will draw attention to the fact that the item went unmaintained at the last frequency and will decrease the probability of again being unaccomplished.

Incorporation of this procedure into the RMP subsystem of BEAMS is strongly recommended. Advantages for this incorporation are as follows. This procedure will provide a listing in priority sequence of the maintenance items in the weekly schedule. Through schedule prioritization, the best available choice for item accomplishment or deletion could be made if a manpower shortage were to develop. Any unaccomplished (overdo) items on the schedule would automatically be multiplied by the specified factor, thereby increasing the priority of those items.

To implement this procedure into BEAMS, minor modifications are recommended. To include the maintenance priority number for each item, the column indicating mission critical would be eliminated. This column presently indicates the status of a maintenance item in relation to its mission importance. If an item is identified as mission critical, a "yes" is placed in the column along side the identified item; if it is not mission critical, the column remains blank. By replacing this column with the maintenance priority number, a value quantifying the importance of maintenance accomplishment for each item in relation to other inventory items is obtained. A clearer perspective is also obtained in distinguishing between mission critical items as well as between critical and noncritical items. Incorporation would affect the schedule format in a manner that would increase the ease of reading and assimilation. This change in format would also be more consistent with the manner in which the schedule is now used. Specifically, the schedule would become tailored to the user needs inducing more effective decision making.

Presently, the RMP fails to recognize those items having a high maintenance priority. As stated in Chapter 1, RMP now competes with other work requirements for available man-hours. This change reduces the probability of meeting RMP's objective. To counter this change will require the best possible utilization of those man-hours which RMP is assigned. The application of the procedure outlined in this research in conjunction with the required set of decision factors will provide management with a tool to effectively deal with this change and to significantly increase the efficiency of program operation. By adopting the findings of this research, decisions concerning the accomplishment of maintenance tasks can be made on the basis of established criteria rather than subjective evaluation.

The results of this research are applicable to any preventative maintenance program. It is recommended that this procedure be implemented Air Force wide immediately. The effective and efficient management of resources in the attainment of RMP's objective is essential in today's environment of limited dollars and manpower.

## FUTURE RESEARCH

Below are listed some follow on studies future researchers may wish to investigate.

1. Investigate if the interface of the EMCS (Environment Monitoring and Control System) with the RMP is effective. As more Air Force bases obtain EMCS, this becomes critical for effective management of the RMP and manpower resources.

2. During interviews with Dayton area organizations, various similarities and differences surfaced concerning the operation of preventative maintenance programs. Investigation into the comparisons and contrasts between the civilian sector and the military sector operation would further assist in improving RMP operation (see Appendix F).

## APPENDIX A

## AF FORM 1841, MAINTENANCE ACTION SHEET

| MAINTENANCE ACTION SHEET | COST CENTER 461 | DESCRIPTION ICE FLAKER | | | MAS NUMBER 017 | |
|---|---|---|---|---|---|---|
| REQUIRED MAINTENANCE ACTIONS | | REFERENCE | STANDARD HOURS | FREQ. | CREW SIZE | HEAVY EQP |
| 1. Check parts for adequate lubrication. Lubricate when necessary | | MFG. CAT. | 0.5 | W | 1 | 2 |
| 2. Clean water freezing system. | | MFG. CAT | 2.0 | M | 1 | 2 |
| 3. Inspect evaporator drum for presence of scale and alignment. Clean and adjust as necessary. | | | | | | |
| 4. Measure clearance between ice cutter or remover blades and evaporator drum. Adjust as necessary. | | | | | | |
| 5. Measure clearance of scraper blade and evaporator drum of rotating-drum ice flaking machines. Adjust as necessary. | | | | | | |

| DATE | NCF INITIALS | DATE | SUPERINTENDENTS INITIALS |
|---|---|---|---|
| 2 Oct. 78 | JBG | 3 Oct. 78 | PB |

AF FORM 1841

AF FORM 1841, MAINTENANCE ACTION SHEET

MAS CONTINUATION
(Additional Required Maintenance Actions)

| FACILITY NUMBER | EQUIPMENT NUMBER | DATE OF ACCOMPLISHMENT | ACTUAL MAN-HOURS | DESCRIPTION OF TASK | CRAFTSMANS INITIALS | RECOMMENDATIONS (Add to required maintenance actions) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | YES | NO | AS REQD. |
| | | | | THIS SIDE OF THE M.A.S. IS | | | | |
| | | | | USED TO IDENTIFY ADDITIONAL | | | | |
| | | | | MAINTENANCE REQUIREMENTS | | | | |
| | | | | FOUND DURING THE SCHEDULED | | | | |
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# APPENDIX B

# BEAMS SUBSYSTEMS AND MANAGEMENT REPORTS

## Executive Management Summaries

Work Control
Cost Accounting
Labor
Material Control
Recurring Maintenance

## Labor and Prime BEEF[1]

BCE[2] Daily Work Schedule
BCE Weekly Schedule Report
Monthly In-Service Work Plan Report
BCE Master Personnel List
BCE Prime BEEF Detail Listing (Listing of assigned AFSCs)
Base Prime BEEF Listing by Team

## Work Control

BCE Work Stoppage List
BCE Work Order Backlog Report
BCE Using Organization Work Order Listing
BCE Cost Limitation Comparison Listing
BCE Completed Work Order Cost Report
BCE Completed Collection Work Order Cost Report

## Cost Accounting

BCE Integrated Transaction List
Schedule of Reimbursements and Refunds
General Officers Quarters Cost Report
Civil Engineer Cost Report
Family Housing Cost Report
BCE Current Month Cost Report
Military Family Housing Current Month Cost Report
Shop Rate Analysis Report - by Cost Center and Category

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[1] BEEF: Base Engineer Emergency Force

[2] BCE: Base Civil Engineering

Real Property Accounting

USAF Real Property Inventory Lists
USAF Real Property Projected Utilization Lists
Facility Vacant Area by Installation
Deleted Installations Records List
Land and Leased Facilities Validation List
USAF Land Change Report
Real Property Work Order Capitalization List
Real Property Voucher Transaction Summaries
Facility Cost Account Cross Reference List
Selected Category Code by Type Construction
Selected Inquiry by Organization Assigned

Maintenance, Repair, and Minor Construction (MAREMIC)

Current FY Program
Prior FY Program
Unfunded Validated Requirements Listings
Current FY Program and Unfunded Requirements - Priority Listing
Base Verification Listing
Month of Award Listing

Recurring Maintenance Program (RMP)

Recurring Maintenance Schedule
Recurring Maintenance Reserved Man-hours
Recurring Maintenance Man-hour Comparison Report
Recurring Maintenance Deleted Items
Cost Comparison Report
RMP Low Cost Record Purge Report

Material Processing

COCESS[3] Item Consumption Summary
COCESS Analysis Report
COCESS Material Requirements List
COCESS Funds Status
BCE Material Due-In Listing

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[3]COCESS: Contractor Operated Civil Engineering Supply Store

## Pesticide Evaluation Summary Tabulation (PEST)

PEST Summary Report

# APPENDIX C

## PERSONAL INTERVIEW QUESTIONNAIRE

1. Why do you have a preventative maintenance program?

2. Does preventative maintenance save you money?

3. Is there any order of priority in which equipment maintenance is performed?

4. How do you decide this order of priority and what decision factors do you use (e.g., age, cost, manufacturers' recommendations, company policy, etc.)?

5. How would you rank these in order of importance?

6. If the situation arises, how would you decide which item would slip from the work schedule?

7. If you are unable to accomplish all of your scheduled maintenance actions, what happens?

8. Are these items given any additional weight in your ordering procedure for the next cycle?

9. How do you incorporate unforeseen or unplanned requirements into the context of your preventative maintenance program?

10. How do you then realign your maintenance schedule due to the loss of available man-hours for maintenance once the unplanned requirements are under control?

APPENDIX D

DEFINITIONS OF DECISION FACTORS

Location--The physical location of a maintenance item. Also considered under location is the movement of men and equipment.

Maintenance Frequency--The specified intervals at which items are maintained (e.g., monthly, quarterly, annually, etc.).

Amount of Use--The actual amount of time an item is in operation (e.g., a particular pump operates 20 hours a day).

Frequency of Use--How many times an item operates (start to stop is equal to one operation) within a specified time frame. For example, a pump may operate 20 hours a day continuously (1 operation) or at one hour intervals (12 operations).

Equipment Type--The specific characteristics of the maintenance item (e.g., pump, compressor, fire alarm, etc.) that differentiates it from other maintenance items.

Equipment Dependence--The reliance on an item by other items for support (e.g., if an item fails, what problems would develop as a result for those items or item dependent on the failed system for support). Consideration should also be given to what function the item serves (e.g., support, mission, recreational, etc.).

Seasonality--This encompasses both on and off season maintenance actions. That is, whether an item is used and maintained during the season of use or whether it is only maintained during the season of no use.

Material--Requirements for the accomplishment of a maintenance task. For example, does the work require bench stock or material that must be ordered.

Equipment Cost--This is to include the initial purchase cost, the amount of money to be lost if the item breaks down beyond repair, and the cost of equipment downtime.

Equipment Age--The actual time a maintenance item has been in operation. How old the equipment is.

Past Data--Historical data on maintenance item relating to past problems encountered or emergencies that have surfaced. Primarily based on personnel experience and past records.

Safety--The safety of persons directly and indirectly involved with the items operation or purpose. This may range from emergency generator lights to a protective shaft housing on a pump motor.

Regulations--Specific directives governing the requirements for maintenance of equipment items.

APPENDIX E

ILLUSTRATIVE EXAMPLE

An illustrative example is presented in this section to provide a comprehensive demonstration of the systematic procedure. Eight maintenance items were randomly selected from Part I, Current Week Recurring Maintenance Schedule from Control Center A, Cost Center #461. This schedule was obtained from the Civil Engineering Squadron at Wright-Patterson AFB. The eight maintenance items were:

1. Air Conditioning System for Navigational Aids
2. Air Compressor System #1 for Heating Plant
3. Air Compressor System #1 for Auto Hobby Shop
4. Air Compressor System #1 for Freight Terminal
5. Air Conditioning Package for Computer Room 133
6. Air Conditioning Package Unit for Command Post
7. Air Compressor System #1 for Tire Shop
8. Air Compressor System #1 for Bomb Maintenance

The decision factors used for this illustrative example included:

1. Amount of Use
2. Equipment Dependence
3. Equipment Type
4. Frequency of Use
5. Location
6. Seasonality

A pairwise comparison chart was then set up as in Figure E-1A. No specific order of the decision factors was required. The only requirement was that each decision factor labeled in a row must be labeled in the respective column. For example, Location was labeled in row #5 and in column #5.

When the pairwise comparison chart was fully labeled with the appropriate decision factors, the process of making pairwise comparisons was started. In Figure E-1A, the pairwise comparison began with the comparison of Equipment Dependence and Amount of Use. Equipment Dependence was selected to be more important than Amount of Use. In the square which intersects these two decision factors, a "+" was inserted to represent this preference. The process was continued with decisions made as to the importance of each factor. At the intersection of each two decision factors, a "+" or "0" was inserted to represent the comparison. The completed pairwise comparison chart is shown in Figure E-1B.

With this completed pairwise comparison chart, the totals of "0"s and "+"s were determined (Figure E-1B). Since the sequence of totals for the row and column totals were the same (e.g., 3-5-4-2-0-1 for the $\Sigma$0's and 3-5-4-2-0-1 for the $\Sigma$+'s), no circularities or irregularities occurred. Since the number one ranked decision factor is that one which has the highest value for the total of +'s, it then

| | AMOUNT OF USE | EQUIPMENT DEPENDENCE | EQUIPMENT TYPE | FREQUENCY OF USE | LOCATION | SEASONALITY | | | | | Σ0's MARGINAL TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AMOUNT OF USE | | + | + | 0 | | | | | | | |
| EQUIPMENT DEPENDENCE | | | | | | | | | | | |
| EQUIPMENT TYPE | | | | | | | | | | | |
| FREQUENCY OF USE | | | | | | | | | | | |
| LOCATION | | | | | | | | | | | |
| SEASONALITY | | | | | | | | | | | |
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| | | | | | | | | | | | |
| MARGINAL TOTALS Σ+'s | | | | | | | | | | | |
| RANK | | | | | | | | | | | |

Fig. E-1A. Pairwise Comparison Chart

| | AMOUNT OF USE | EQUIPMENT DEPENDENCE | EQUIPMENT TYPE | FREQUENCY OF USE | LOCATION | SEASONALITY | | | | | Σ0's MARGINAL TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AMOUNT OF USE | | + | + | 0 | 0 | 0 | | | | | 3 |
| EQUIPMENT DEPENDENCE | 0 | | 0 | 0 | 0 | 0 | | | | | 5 |
| EQUIPMENT TYPE | 0 | + | | 0 | 0 | 0 | | | | | 4 |
| FREQUENCY OF USE | + | + | + | | 0 | 0 | | | | | 2 |
| LOCATION | + | + | + | + | | + | | | | | 0 |
| SEASONALITY | + | + | + | + | 0 | | | | | | 1 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| MARGINAL TOTALS Σ+'s | 3 | 5 | 4 | 2 | 0 | 1 | | | | | |
| RANK | 3 | 1 | 2 | 4 | 6 | 5 | | | | | |

Fig. E-1B. Pairwise Comparison Chart

follows that Equipment Dependence became the number one rank. The remaining decision factors were then ranked in order of decreasing totals of +'s (Figure E-1B).

In order to determine the decision factor weights, the summation of the ranks was determined. From Figure E-1B, this sum was then 3+1+2+4+6+5=21. The respective decision factor weights were determined by dividing this sum by the rank number of the decision factor as follows:

| Decision Factor | Rank | Decision Factor Weight |
|---|---|---|
| Amount of Use | 3 | 21/3 = 7 |
| Equipment Dependence | 1 | 21/1 = 21 |
| Equipment Type | 2 | 21/2 = 10.5 |
| Frequency of Use | 4 | 21/4 = 5.25 |
| Location | 6 | 21/6 = 3.5 |
| Seasonality | 5 | 21/5 = 4.2 |

This step concludes the determination of decision factor weights and moves the process to the calculation of the maintenance priority number.

To calculate the maintenance priority number, a Rank Order Worksheet was developed. This worksheet, shown in Figure E-2A, provides a convenient means of calculating the priority number. The worksheet includes the item description, the decision factors, and their respective weights.

All decision factors for the maintenance items used in this example were then assigned a utility value between 1 and 7, depending upon the relative importance of each decision factor. Figure E-2A shows the maintenance priority number for the Air Conditioning System for Navigational Aids.

This procedure was accomplished for the other remaining maintenance items. In each case, the utility value was multiplied by the decision factor weight. These intermediate priority values were then summed to give the maintenance priority numbers (Figures E-2B through E-2H).

The final step of the systematic procedure example is the prioritization of maintenance items. In this step, all of the maintenance items were sorted using the maintenance priority number. The results of this step are shown in Table E-1.

Two sidenotes to this example should be addressed. These are the possible occurrence of identical maintenance priority numbers and the situation of an overdo item. In the case of identical priority numbers, the tie would have been broken by the shop supervisor or foreman. Since no quantitative factors can determine the importance of the items, experience and judgment of the shop supervisor or foreman would probably come to play as the determinant of importance. For the situation of an overdo item, an additional factor will be applied to the maintenance priority number. For example, suppose rank #4, the Air Compressor System #1 for Heating Plant, had been an overdo item. In order to insure that it would be maintained next week, its maintenance number will be multiplied by 10. This will

EQUIPMENT DESCRIPTION: Air Conditioning System for Navigational Aids

CONTROL CENTER: A

COST CENTER: 461

RATING SCALE

NEVER — SOMETIMES — ALWAYS

1 2 3 4 5 6 7

| DECISION FACTOR | A UTILITY VALUE (1-7) | B *WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 7 | 7 | 49 |
| EQUIPMENT DEPENDENCE | 7 | 21 | 147 |
| EQUIPMENT TYPE | 6 | 10.5 | 63 |
| FREQUENCY OF USE | 5 | 5.25 | 26.25 |
| LOCATION | 4 | 4.2 | 16.8 |
| SEASONALITY | 5 | 3.5 | 17.5 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 319.55 |

*Value obtained from pairwise comparison

Fig. E-2A. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Compressor System #1 for Heating Plant

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

| NEVER | | | SOMETIMES | | | ALWAYS |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| DECISION FACTOR | A UTILITY VALUE (1-7) | B *WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 6 | 7 | 42 |
| EQUIPMENT DEPENDENCE | 5 | 21 | 105 |
| EQUIPMENT TYPE | 4 | 10.5 | 42 |
| FREQUENCY OF USE | 4 | 5.25 | 21 |
| LOCATION | 5 | 4.2 | 21 |
| SEASONALITY | 2 | 3.5 | 7 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 238 |

*Value obtained from pairwise comparison

Fig. E-2B. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Compressor System #1 for Auto Hobby Shop

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

NEVER — SOMETIMES — ALWAYS

1 2 3 4 5 6 7

| DECISION FACTOR | A<br>UTILITY VALUE (1-7) | B<br>*WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 3 | 7 | 21 |
| EQUIPMENT DEPENDENCE | 3 | 21 | 63 |
| EQUIPMENT TYPE | 2 | 10.5 | 21 |
| FREQUENCY OF USE | 1 | 5.25 | 5.25 |
| LOCATION | 1 | 4.2 | 4.2 |
| SEASONALITY | 1 | 3.5 | 3.5 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 98.95 |

*Value obtained from pairwise comparison

Fig. E-2C. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Compressor System #1 for Freight Terminal

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

| NEVER | | | SOMETIMES | | | ALWAYS |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| DECISION FACTOR | A UTILITY VALUE (1-7) | B *WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 5 | 7 | 35 |
| EQUIPMENT DEPENDENCE | 4 | 21 | 84 |
| EQUIPMENT TYPE | 4 | 10.5 | 42 |
| FREQUENCY OF USE | 2 | 5.25 | 10.5 |
| LOCATION | 4 | 4.2 | 16.8 |
| SEASONALITY | 1 | 3.5 | 3.5 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 191.8 |

*Value obtained from pairwise comparison

Fig. E-2D. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Conditioning Package for Computer Room 133

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

NEVER — SOMETIMES — ALWAYS

1 2 3 4 5 6 7

| DECISION FACTOR | A UTILITY VALUE (1-7) | B *WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 6 | 7 | 42 |
| EQUIPMENT DEPENDENCE | 7 | 21 | 147 |
| EQUIPMENT TYPE | 7 | 10.5 | 73.5 |
| FREQUENCY OF USE | 5 | 5.25 | 26.25 |
| LOCATION | 2 | 4.2 | 8.4 |
| SEASONALITY | 6 | 3.5 | 21 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 318.15 |

*Value obtained from pairwise comparison

Fig. E-2E. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Conditioning Package Unit for Command Post

CONTROL CENTER: A

COST CENTER: 461

RATING SCALE

| NEVER | | | SOMETIMES | | | ALWAYS |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| DECISION FACTOR | A<br>UTILITY VALUE (1-7) | B<br>*WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 5 | 7 | 35 |
| EQUIPMENT DEPENDENCE | 7 | 21 | 147 |
| EQUIPMENT TYPE | 7 | 10.5 | 73.5 |
| FREQUENCY OF USE | 4 | 5.25 | 21 |
| LOCATION | 3 | 4.2 | 12.6 |
| SEASONALITY | 5 | 3.5 | 17.5 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 306.6 |

*Value obtained from pairwise comparison

Fig. E-2F. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Compressor System #1 for Tire Shop

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

NEVER — SOMETIMES — ALWAYS

1 2 3 4 5 6 7

| DECISION FACTOR | A<br>UTILITY VALUE (1-7) | B<br>*WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 4 | 7 | 28 |
| EQUIPMENT DEPENDENCE | 4 | 21 | 84 |
| EQUIPMENT TYPE | 4 | 10.5 | 42 |
| FREQUENCY OF USE | 2 | 5.25 | 10.5 |
| LOCATION | 1 | 4.2 | 4.2 |
| SEASONALITY | 1 | 3.5 | 3.5 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma$(AXB)) | | | 172.2 |

*Value obtained from pairwise comparison

Fig. E-2G. Rank Order Worksheet

EQUIPMENT DESCRIPTION: Air Compressor System #1 for Bomb Maintenance

CONTROL CENTER: A

COST CENTER: 461

## RATING SCALE

NEVER — SOMETIMES — ALWAYS

1 2 3 4 5 6 7

| DECISION FACTOR | A UTILITY VALUE (1-7) | B *WEIGHT | A x B |
|---|---|---|---|
| AMOUNT OF USE | 4 | 7 | 28 |
| EQUIPMENT DEPENDENCE | 5 | 21 | 105 |
| EQUIPMENT TYPE | 5 | 10.5 | 52.5 |
| FREQUENCY OF USE | 3 | 5.25 | 15.75 |
| LOCATION | 4 | 4.2 | 16.8 |
| SEASONALITY | 4 | 3.5 | 14 |
| | | | |
| | | | |
| MAINTENANCE PRIORITY NUMBER ($\Sigma(A \times B)$) | | | 232.05 |

*Value obtained from pairwise comparison

Fig. E-2H. Rank Order Worksheet

Table E-1

Summary of Results

| Rank Priority | Maintenance Item | Priority Number |
|---|---|---|
| 1 | Air Conditioning System for Navigational Aids | 319.55 |
| 2 | Air Conditioning Package for Computer Room 133 | 318.15 |
| 3 | Air Conditioning Package Unit for Command Post | 306.6 |
| 4 | Air Compressor System #1 for Heating Plant | 238 |
| 5 | Air Compressor System #1 for Bomb Maintenance | 232.05 |
| 6 | Air Compressor System #1 for Freight Terminal | 191.8 |
| 7 | Air Compressor System #1 for Tire Shop | 172.2 |
| 8 | Air Compressor System #1 for Auto Hobby Shop | 98.95 |

yield a new maintenance number of 2380. This high value will insure that it will be given first priority over the rest of the items for the following week.

# APPENDIX F

# SUPPLEMENTAL RESEARCH FINDINGS

The private sector organizations were selected on the basis that they performed functions that parallel those found in the Air Force. However, even though all those interviewed shared the common element of preventative maintenance operations, the manner and constraints under which those operations are carried out differ to some degree from those experienced in the Air Force Civil Engineering Recurring Maintenance Program (CERMP). Before discussing these differences, two important similarities need to be mentioned. The first is the shared emphasis placed on preventative maintenance. Consistently throughout the interviews, the importance placed on preventative maintenance could not be overemphasized by the respective shops and organizations. The second similarity is in the decision factors used in the determination of an item's priority. Although some variance did exist, most personnel interviewed were in agreement as to which decision factors should be used in job prioritization. The variance can be accounted for in the fact that although each organization and shop maintained a preventative maintenance program, the goals and objectives differed such that certain decision factors highly emphasized by one organization or shop carried very little weight in another.

A significant difference that surfaced during this research between the public and private sector maintenance personnel was profit. It is a general fact that public organizations are suppose to be nonprofit seeking. Preventative maintenance as used in the Air Force is a method to minimize cost and to increase the life expectancy of equipment. There is no motive in this program to "turn a profit". However, this is not the case in the private sector. This fact was best highlighted during the interview with Delco Products Division. Delco's preventative maintenance program is almost totally mechanized. Automation of preventative maintenance actions was put into effect to minimize equipment downtime. Operating 24 hours per day, the number of hours a piece of equipment is out of operation the cost of that operation increases. Delco has found that through automated maintenance action and appropriate back-up systems, a lesser cost is incurred than if a manual work force performed the maintenance tasks which would require additional equipment downtime. Also, stopping a machine for maintenance would incur more cost that if the machine was allowed to run until failure. Therefore, a reactive preventative maintenance program was followed on equipment not equiped for automative maintenance action. An additional reason Delco operated in this mode is that much of the machinery in operation is self-manufactured. As a result, they were a sole source of parts. In their minds, it was a benefit to operate a reactive program and put out fires as needed. It is fairly evident that a major difference in operation and philosophy exists between Delco's preventative maintenance and the Air Force CERMP.

At Wright State University, a slightly different approach was taken in the preventative maintenance operations. Instead of a weekly schedule being published, those items requiring maintenance during a one month period were listed and given to a separate preventative maintenance work force to accomplish. This preventative maintenance work force was rotated periodically by management so as not to introduce set employees to the repetitive tasks of preventative maintenance. Wright State has found that by using a one month schedule and a rotating work force, more preventative maintenance and more quality maintenance was being performed. Also, backlogs of work were almost eliminated. A point to mention is that almost no pressure is applied to the employees assigned preventative maintenance duty. A check is usually made by management during the last week of the month to check progress; other than this, no external pressure is applied. Wright State reported that after the initial breakin period (approximately 1-2 years), their program is operating efficiently and effectively. They attribute a large portion of this success to the allowance of worker freedom and the ability to schedule a total month's effort.

Recently, Wright State has added a computer system comparable in concept to the Air Force EMCS (Environmental Monitoring and Control System) to aid in the maintenance operation of the campus. At the time of this research, they were just beginning to use the computer to assist in preventative maintenance operations. Presently, a manual system is used to identify those items in need of maintenance. However, as more computer capability is introduced, their goal is to automate the system as the Air Force has done using BEAMS.

Perhaps the organization which conducted a program most similar to the Air Force was Miami Valley Hospital. Miami Valley conducts preventative maintenance on a work order basis with the maintenance items broken down by craft (e.g., carpenter, metal, HVAC, etc.). The main difference between the two programs is that Miami Valley's program is manual rather than automated. However, as mentioned, there are more similarities than differences. Because the hospital provides health services for the public, it must operate under certain laws, codes, and regulations set forth by federal, state, and local agencies. This requires that meticulous records be kept and procedures followed. The decision factors that are used by Miami Valley are often dictated by these laws, codes, and regulations. However, in the generic form, they are the same as those identified by the other organizations interviewed. Due to the heavy amount of regulation, preventative maintenance operations at Miami Valley appear to be more rigid than those experienced in the Air Force.

The program in operation at Dayton International Airport was in many ways similar in operation to Miami Valley Hospital and the RMP. Again, work orders were used and the system was operated manually. Heavy emphasis was placed on past records and files were maintained from acquisition to departure from inventory. The maintenance work force shared preventative maintenance responsibilities. Operating from a central shop, keeping track of maintenance items could easily be accomplished. The responsibility of maintenance was to keep the airport operational. In order to accomplish this mission, it was essential to have all equipment fully capable when needed. Accomplishing preventative maintenance was listed as high priority by the maintenance department at Dayton International. They considered their operation to run efficiently using a manual work force and a manual record keeping system.

In review of the interviews conducted for this research, it is evident that even though all organizations and shops interviewed operated a preventative maintenance program, the operation and philosophy of those programs differed in each case. Although each program was pursuing the same goal through preventative maintenance operations, a key factor was that each program was designed to meet the needs of the user organization. If the good points of these programs were to be highlighted, they would only be valid within the context of the user's environment. The main thrust is that a method of operation which has been proven successful in one organization may not be suited to the needs of another organization (this is not to say that certain adaptive measures could not be applied). An example will illustrate this point.

The preventative maintenance operation at Wright State University uses a rotating but specified preventative maintenance work force. As determined from the interview with Wright State maintenance personnel, this has been proven successful. However, if a similar type operation was to be employed in the Air Force CERMP, a manpower shortage would preclude any success. This is based on statements made during interviews with Wright-Patterson maintenance personnel concerning the possible use of such a program. This apparent failure, however, could easily be reversed if additional manpower were provided to the CE shops. Since this task would require much effort, the adaption of a separate preventative maintenance work force into the RMP would not be impossible, but highly improbable. A point to be stressed, however, is that although differences did exist, the use of the identified decision factors by maintenance personnel for job prioritization are factors that may be used without a loss of validity to meet the needs of any organization.

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